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Analysis and Design of Water Distribution Network Using EPANET for Chirala Municipality in Prakasam District of Andhra Pradesh

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Abstract— The present system of supply adopted in Chirala municipality is an intermittent supply and the network adopted is a dead end system. This system of supply of water in Chirala municipality may or may not be reliable to the upcoming years. Hence the research is all about the analysis of the existing network and concludes about the reliability on the network for the future. The analysis is carried out based on various public demands, quantities of inflows and out flows of the over-head reservoirs. This analysis provides the information about various demands, losses, and uses of the public. The design of a new network of supply will make the municipality be aware of the new demands, rate of increase in the demands. The design is made keeping in view of the population growth rate, and the developing town. The design brings out an improvement in the existing network.

***Index Terms*— Water Distribution, Network Analysis, EPANET, Population forecast, water demand, nodal demand.**

I. Introduction

In 2010, about 85% of the global population (6.74 billion people) had access to piped water supply through house connections. Water supply networks are part of the master planning of communities, counties, and municipalities. Their planning and design requires the expertise of city planners and civil engineers, who must consider many factors, such as location, current demand, future growth, leakage, pressure, pipe size, pressure loss, firefighting flows, etc.

Water supply systems get water from a variety of locations, including groundwater, surface water (lakes and rivers). The water is then, in most cases, purified, disinfected through chlorination and sometimes fluoridated. Treated water then either flows by gravity or is pumped to reservoirs, which can be elevated such as water towers or on the ground. The water is then fed into the distribution systems.

The analysis is done using the software EPANET. EPANET is software that models water distribution piping systems. EPANET is public domain software that may be freely copied and distributed. It is a Windows 95/98/NT/XP program. EPANET performs extended period simulation of the water movement and quality behavior within pressurized pipe networks.

Pipe networks consist of pipes, nodes (junctions), pumps, valves, and storage tanks or reservoirs. EPANET tracks:

- The flow of water in each pipe,
- The pressure at each node,
- The height of the water in each tank,
- The type of chemical concentration throughout the network during a simulation period,
- Water age,
- Source, and
- Tracing.

II. OBJECTIVE

The objective of the distribution system is to supply water to each and every house, industrial plants and public places. Each house must be supplied with sufficient quantity of water at the desired pressure. Therefore the water has to be taken to the roads and streets in the city and finally to the individual houses. This function of carrying the water from the treatment plant to the individual homes is accomplished through a well-planned distribution system. A distribution system therefore consists of pipe lines of various sizes for carrying water to the streets; valves for controlling the flow, service connections to the individual homes, distribution reservoirs for storing the water to be fed into the distribution pipes. The water may either be pumped directly into the distribution pipes, or it may be first stored in a distribution reservoir and then fed into the distribution pipes.

The main purpose of the distribution systems is to develop adequate water pressure at various points i.e., at the consumer's tap and the choice of the distribution and its elevation with respect to the location of the water treatment plants.

III. STUDY AREA

Chirala is one of the important towns in the Prakasam district of Andhra Pradesh. The town was constituted as municipality on 01.04.1947 and upgraded as 1st grade municipality on 01.10.1965. The area of the town is 13.30 sq.km with 33 election wards.

Chirala is located at a distance of 6km from Bay of Bengal. The town is geographically situated in between the latitudes of 50^0.40’ to 15^0.50’ North and longitudes of 80^0.28’ to 80^0.25’ East.

The built up area of the town is combined to the east while mostly agricultural lands are in the western side of the town. The town is developed in two bits namely Chirala and Perala and running parallel to the railway track for a length of about 4km. The town is surrounded by two vagu courses namely Wada on west and Kunderu on east. The south to north separating the major part of town on eastern side. The major district road namely Guntur-Bapatla-Chinaganjam road is passing through this town parallel to railway track. Similarly the state highway the national highway-5 at Chilakaluri peta which is at a distance of 40km. Some new colonies such as Mahatma Gandhi Cloth Merchants Colony and some other colonies have been developed on southern side of this town.

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This town is an important commercial centre in respect to cloth business and cashew nut production.

Fig 1: Map of Study area

Table I: TOWN PROFILE

No. of Houses	19,353
No. of ELSRs	5
Total installed capacity of water supply	10.00MLD
No. of HSCs	6900
No. of S.S. tanks	1
No. of. degree collages	Government-1
	Private-4
No. of. Junior colleges	Private-10
	Aided-1
No. of technical educational institutions	I.T.I-1
No. of. High schools	Govt./Municpality -3
	Private-5
No. of. Upper primary schools	Municipality-1
No. of. Primary schools	Municipality-12
	Private-21
No. of. Parks	6
No. of. Play grounds	2
No. of. Hospitals	Government-1
	Private-36
No. of. Municipal dispensaries	2
No. of urban heath centres	3
No. of Anganwadi centres	83
No. of community halls	10
No. of burial grounds	7
Major industries	I.T.C.LTD, ILTD DIVISION

IV. LITERATURE REVIEW

Prof Dr.Mohammed Ali I. Al-Hashim, Nassrin J. Al-Mansori[1] presented in his research, the reality of the potable water services in AL-Diwaniya City was studied, it in two essential lines:

First, the analysis of water distribution in the city trunk network, by using the program (pipe++) version 1998 to get the quantities and the directions of discharges water. Also it uses head pressure in some related network nodes. Measurements were made, infield, from each region to estimate head in each trunk in order to specify the regions that suffer from shortage in water.

The objective of the distribution system is to supply water to each and every house, industrial plants and public places. Each house must be supplied with sufficient quantity of water at the desired pressure. [lencastre 1987]. Nilsen (1989): studied different methods of pipe networks for analysis. He formulated the flow equations in terms of both pipes discharge and energy heads and the problem reformulated in terms of vectors and matrices. To solve the problem, three different methods were used; the linear theory, Newton-Raphson and the general-purpose optimization algorithm to the problem. The method shows that the formulating flow resistance in terms of energy heads has two great advantages, the reduced system, and easy to implement a computer program that solves the system. The disadvantages are it is difficult to get a good starting vector and the convergence may be very slow. Formulating the flow resistance in terms of pipe discharge has advantage of reducing the number of primary unknowns (m-n) to (n/2), where (n) is the number of primary unknowns, and has one disadvantage of the need for computing a basis for the complete solution to the continuity equations. Demonstrated that an efficient method for analysing pipe networks consists in solving the generalized loop equations by means of the Newton-Raphson method combined with the linear theory method as a simple and robust starting procedure.

Shibu A. and M. Janga Reddy[2] presented, Water distribution system modelling problems are associated with large number of variables which are uncertain in nature. The uncertainties are due to (i) formula used (ii) coefficients in the formula and (iii) imprecise knowledge of the values of various parameters. Usually uncertainty exists in nodal demands and the uncertainty associated with nodal demands has to be considered for better design of water distribution networks. A two phase methodology for the least cost design of water distribution network based on fuzzy set theory and cross entropy method is proposed. The uncertain demands are considered as fuzzy sets, and the diameters for each pipe are selected from the commercially available diameters by cross entropy method. The model coded in MATLAB is linked to EPANET tool kit for hydraulic simulation. The proposed methodology was tested on Hanoi water distribution network, and the solutions obtained are compared with well-known deterministic solutions from literature. The methodology is found to be effective in dealing with uncertainty in input parameters represented as fuzzy sets, and also the discrete diameters are very well handled by cross entropy method.

The vast majority of mathematical models in engineering use deterministic approaches to describe various processes and systems. However, all real life problems incorporate uncertainty in one way or another. Water distribution system modelling problems are associated with a large number of variables which are uncertain in nature. The uncertainties are due to formula used, coefficients in the formula, and imprecise knowledge of the values of various parameters.

V. METHODOLOGY

POPULATION FORECASTING:

Design of water supply and sanitation scheme is based on the projected population of a particular city or town, estimated for the design period. Any underestimated value will make system inadequate for the purpose intended; similarly overestimated value will make it costly. Change in the population of the city over the years occurs, and the system should be designed taking into account of the population at the end of the design period.

Factors affecting changes in population are:

- Increase due to births
- Decrease due to deaths
- Increase/ decrease due to migration
- Increase due to annexation.

The present and past population record for the city can be obtained from the census population records. After collecting these population figures, the population at the end of design period is predicted using various methods as suitable for that city considering the growth pattern followed by the city.

Population forecasting is based on the following methods

- Arithmetical Increase Method
- Geometrical Increase Method
- Incremental Increase Method
- Graphical Method
- Comparative Graphical Method
- Master Plan Method
- Logistic Curve Method

Table II: VARIOUS TYPES OF WATER DEMANDS

S.NO	TYPE OF DEMAND	QUANTITY
1	Domestic water demand	135 to 225 l/h/d
2	Industrial water demand	50 liters/person/day
3	Institution and commercial water demand	20 to 50 l/h/d
4	Demand for public uses	10 l/h/d
5	Fire demand	1 l/h/d
6	Water required compensating losses in wastes, thefts.	15 % of the total compensation

DISTRIBUTION SYSTEM

Methods of Distribution

For efficient distribution it is required that water should reach to every consumer with required rate of flow. Therefore, some pressure in pipe lines is necessary, which should force the water to reach at every place. Depending upon the methods of distribution, the distribution system is classified as follows:

(1) Gravity system
(2) Pumping system
(3) Dual system

LAYOUTS OF DISTRIBUTION SYSTEM

Generally in practice there are four different systems of distribution system which are used. Depending upon their layout and direction of supply, they are classified as follows:

1. Dead end or tree system
2. Grid iron system
3. Circular or ring system
4. Radial system
5.

SYSTEMS OF SUPPLY

The water may be supplied either continuously for 24 hours of the day or may be supplied intermittently only for the peak periods during morning and evening. The intermittent supply system may sometimes lead to some saving in water consumption due to losses occurring for lesser time and more vigilant use of water by consumers. The intermittent supply system is largely employed in India.

EPANET

Overview:

The EPANET computer model used for water distribution network analysis is composed of two parts: (1) The input data file and (2) The EPANET computer program. The data file defines the characteristics of the pipes, the nodes (ends of the pipe), and the control components (such as pumps and valves) in the pipe network. The computer program solves the nonlinear energy equations and linear mass equations for pressures at nodes and flow rates in pipes.

Input data file:

The EPANET input data file, created automatically by MIKE NET, includes descriptions of the physical characteristics of pipes and nodes, and the connectivity of the pipes in a pipe network system. The user can graphically layout the water distribution network, if desired. Values for the pipe network parameters are entered through easy-to-use dialog boxes. MIKE NET then creates the EPANET input data file in the format required to run the analysis. The pipe parameters include the length, inside diameter, minor loss coefficient, and roughness coefficient of the pipe. Each pipe has a defined positive flow direction and two nodes. The parameters of nodes consist of the water demand or supply, elevation, and pressure or hydraulic grade line.

EPANET computer program:

The EPANET computer program was developed by the U.S. EPA (Environmental Protection Agency). The program computes the flow rates in the pipes and then HGL at the nodes. The calculation of flow rates involves several iterations because the mass and energy equations are nonlinear. The number of iterations depends on the system of network equations and the user-specified accuracy.

A satisfactory solution of the flow rates must meet the specified accuracy, the law of conservation of mass and energy in the water distribution system, and any other requirements imposed by the user. The calculation of HGL requires no iteration because the network equations are linear. Once the flow rate analysis is complete, the water quality computations are then performed.

Table III: Pipe head loss formulae:

Formula	Resistance coefficient(a)	Flow Exponent (b)
Hazen-Williams	$4.72C^{-1.85}d^{-4.87}L$	1.85
Darcy-Weisbach	$0.0252f(\varepsilon,d,q)\ d^{-5}L$	2
Chezy-Manning(full pipe flow)	$4.66n^{2}d^{-5.33}L$	2

Where, C = Hazen-Williams roughness coefficient
e = Darcy-Weisbach roughness coefficient, ft
f = friction factor (dependent on e, d, and q)
d = pipe diameter, ft
L = pipe length, ft

Methods of allocation of demand

1) Areal method of allocation
2) Point method of allocation
3) GIS based method of allocation

Table IV: Roughness coefficients for new pipes:

Material	Hazen-Williams C	Darcy-Weisbach ε, mill feet	Manning's n
Cast Iron	130-140	0.85	0.012-0.015
Concrete or Concrete Lined	120-140	1.0-10	0.012-0.017
Galvanized Iron	120	0.5	0.015-0.017
Plastic	140-150	0.005	0.011-0.015
Steel	140-150	0.15	0.015-0.017
Vitrified Clay	110	-	0.013-0.015

DESIGN

POPULATION FORECASTING:

TABLE V: Population Data of the past 4 decades:

Year	**Population**	**Incremental per decade**	**%Incremental per decade**	**Incremental increase**	**Decrease in % increment**
1971	54461			8485	
		17579	32.28		
1981	72040			8758	20.04
		8821	12.24		
1991	80861			4712	7.14
		4109	5.1		
2001	84970			1740	2.31
		2369	2.79		
2011	87339				

TABLE VI: Estimated Population Data for the next 3 decades:

Arithmetical Increase Method:		**Incremental Increase Method:**	
Year	**Estimated Population**	**Year**	**Estimated Population**
2021	95607	2021	94571
2031	103875	2031	100750
2041	112143	2041	105875
Geometrical Increase Method:		**Incremental Increase Method:**	
Year	**Estimated Population**	**Year**	**Estimated Population**
2021	100833	2021	94352
2031	116411	2031	94928
2041	134397	2041	88463

DETERMINATION OF QUANTITY OF WATER

Design population = 1, 34,398

After forecasting the population, the quantity of water to be treated and supplied should be calculated, for this we have adopted the standards specified by IS 1172-1971 and from the manual on water supply and treatment prepared by the Central Public Health and Environmental Engineering Organization.

Table VII: Determination of Quantity of Water

PURPOSE	**QUANTITY**
For domestic use	0.074×10^6 lit/day
For hospitals including laundry	0.034×10^6 lit/day
Private hospitals	0.36×10^6 lit/day
For Municipal dispensaries	0.014×10^6 lit/day
For Urban Health Centers	0.024×10^6 lit/day
Government colleges	0.011×10^6 lit/day
Private colleges	0.027×10^6 lit/day.
Junior Private colleges	0.225×10^6 lit/day
Junior Aided colleges	0.0225×10^6 lit/day
Technical educational institutions	0.29×10^6 lit/day
High schools	0.018×10^6 lit/day
Upper primary schools	0.002×10^6 lit/day
Primary schools	0.074×10^6 lit/day
Cinema halls	0.022×10^6 lit/day
TOTAL DEMAND	**19.123×10^6 lit/day**

PROCEDURE FOR THE DEVELOPMENT OF AN EPANET FILE: The layout of the distribution network is drawn based on the existing road pattern in an AUTOCAD file. This network is now converted into an EPANET file by using various softwares such as "EPACAD". EPACAD converts the AUTOCAD file to EPANET file by considering intersections of the lines as nodes and lines as links.

Common nodal data:

Nodal elevation is taken in between 4.5m to 5.5m from the mean sea level.

Common link data:

1) Length of the pipe is taken as the road length.
2) The diameter of the pipe is considered based on the purpose served by the pipe, such as main, sub main, branch pipes.
3) Pipe roughness coefficient is taken 145, since plastic pipes are used.

Calculation of nodal demand:

Unit area demand is the ratio of total demand of water required by the town to the total area of the town.

Unit area demand for Chirala municipality = $19.123 \times 10^6/13.30\times10^6$ lit/m^2/day = 1.438 lit/ m^2/day

In this analysis areas are calculated using AUTOCAD software and the above procedure is adopted to calculate the demands of each node and is allocated to the node. This demand is directly given directly to respective nodes.

Table VIII: Input File

Link Id	Start Node	End Node	Length (m)	Diameter (mm)
1	1	2	15	400
2	3	2	15	288
3	3	4	75	288

4	4	5	60	288
5	5	6	130	288
6	6	7	45	288
7	6	8	45	100
8	8	9	20	100
9	8	10	45	100
10	10	11	90	100
11	11	12	60	100
12	12	13	75	100
13	14	15	45	183
14	13	15	65	100
15	14	2	45	100
16	13	16	50	100
17	16	17	40	100
18	3	13	48	100
19	4	12	48	100
20	5	11	48	146
21	10	23	75	100
22	16	18	75	100
23	18	19	65	100
24	19	20	10	146
25	20	21	35	100
26	11	19	50	146
27	21	22	65	100
28	16	22	120	100
29	20	23	80	146
30	24	23	65	146
31	25	24	25	146
32	26	25	45	100
33	26	27	75	146
34	27	28	40	146
35	28	7	15	146
36	28	29	150	100
37	29	30	35	183
38	30	27	135	100
34	27	28	40	146
35	28	7	15	146
36	28	29	150	100
37	29	30	35	183
38	30	27	135	100
39	30	31	75	183
40	31	32	50	100

VI. RESULTS AND DISCUSSION:

Table IX: Link Results

LID	Flow LPS	Velocity m/s	Unit Head loss m/km	Status
1	78.72	0.63	0.83	Open
2	-70.54	1.08	3.36	Open
3	48.39	0.74	1.67	Open
4	43.69	0.67	1.38	Open
5	36.78	0.56	1	Open
6	36.68	0.56	1	Open
7	-0.23	0.03	0.01	Open
8	0.06	0.01	0	Open
9	-0.45	0.06	0.05	Open
10	-2.04	0.26	0.82	Open
11	-1.11	0.14	0.26	Open
12	0.33	0.04	0.03	Open
13	0.8	0.03	0.01	Open
14	3.84	0.49	2.65	Open
15	-8.07	1.03	10.46	Open
16	1.66	0.21	0.56	Open
17	0.12	0.02	0	Open
18	5.52	0.7	5.18	Open
19	3.75	0.48	2.53	Open
20	6.56	0.39	1.13	Open
21	1.27	0.16	0.34	Open
22	0.56	0.07	0.08	Open
23	1.13	0.14	0.27	Open
24	6.21	0.37	1.02	Open
25	1.17	0.15	0.29	Open
26	5.26	0.31	0.75	Open
27	-1.46	0.19	0.44	Open
28	0.74	0.09	0.13	Open
29	4.85	0.29	0.64	Open
30	-5.79	0.35	0.9	Open
31	-4.19	0.25	0.49	Open
32	-1.18	0.15	0.3	Open
33	-2.98	0.18	0.26	Open
34	-4.75	0.28	0.62	Open
35	-6.68	0.4	1.17	Open
36	1.63	0.21	0.54	Open
37	-1.19	0.05	0.02	Open
38	-1.4	0.18	0.41	Open
39	-0.15	0.01	0	Open
40	-0.79	0.1	0.14	Open

Table X: Node Results

Node Id	Demand LPS	Head (m)	Pressure (m)
2	0.11	19.99	16.74
3	0.23	19.94	16.59
4	0.29	19.81	16.41
5	0.35	19.73	15.98
6	0.33	19.6	15.2
7	0.12	19.55	14.5

8	0.16	19.6	14.6
9	0.06	19.6	14.5
10	0.31	19.6	15.35
11	0.37	19.67	14.97
12	0.42	19.69	15.74
13	0.35	19.69	16.19
14	0.21	19.52	16.22
15	0.71	19.52	16.27
16	0.23	19.66	16.06
17	0.12	19.66	16.26
18	0.35	19.66	15.61
19	0.19	19.64	15.39
20	0.19	19.63	15.28
21	0.3	19.62	15.17
22	0.26	19.65	15.85
23	0.33	19.58	14.83
24	0.19	19.52	14.62
25	0.16	19.51	14.41
26	0.3	19.49	14.29
27	0.37	19.51	14.31
28	0.3	19.54	14.39
29	0.1	19.46	14.36
30	0.36	19.46	14.41
31	0.27	19.46	13.96
32	0.2	19.46	14.06
33	0.19	19.47	14.12
34	0.26	19.46	13.86
35	0.18	19.46	14.01
36	0.32	19.47	14.07
37	0.33	19.49	14.14
38	0.31	19.5	14.3
39	0.3	19.5	14.35
40	0.35	19.51	14.56

Fig 2: Demand Distribution Network Diagram

Fig 3: Pressure Distribution Network Diagram

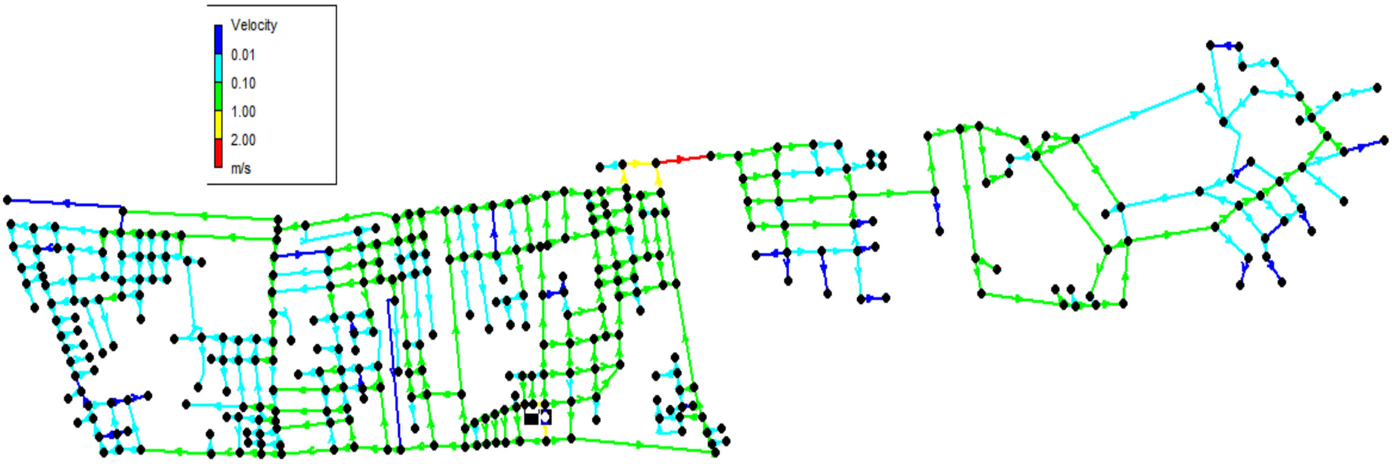

Fig 4: Velocity Distribution Network Diagram

VII. CONCLUSION

The present distribution network laid in Chirala municipality consists of five zones. This network is laid according to those days requirement and is not suitable to the future (2041) needs and demands.

Hence a new network is to be laid to meet future demands and to reach the consumer at the door step.

The newly laid network is laid according to the road pattern using master plan in view of the extension of the town in future. Two new zones were identified for the construction of reservoirs to meet the needs of those zones respectively. The general layout of the municipality representing the new zones is as follows.

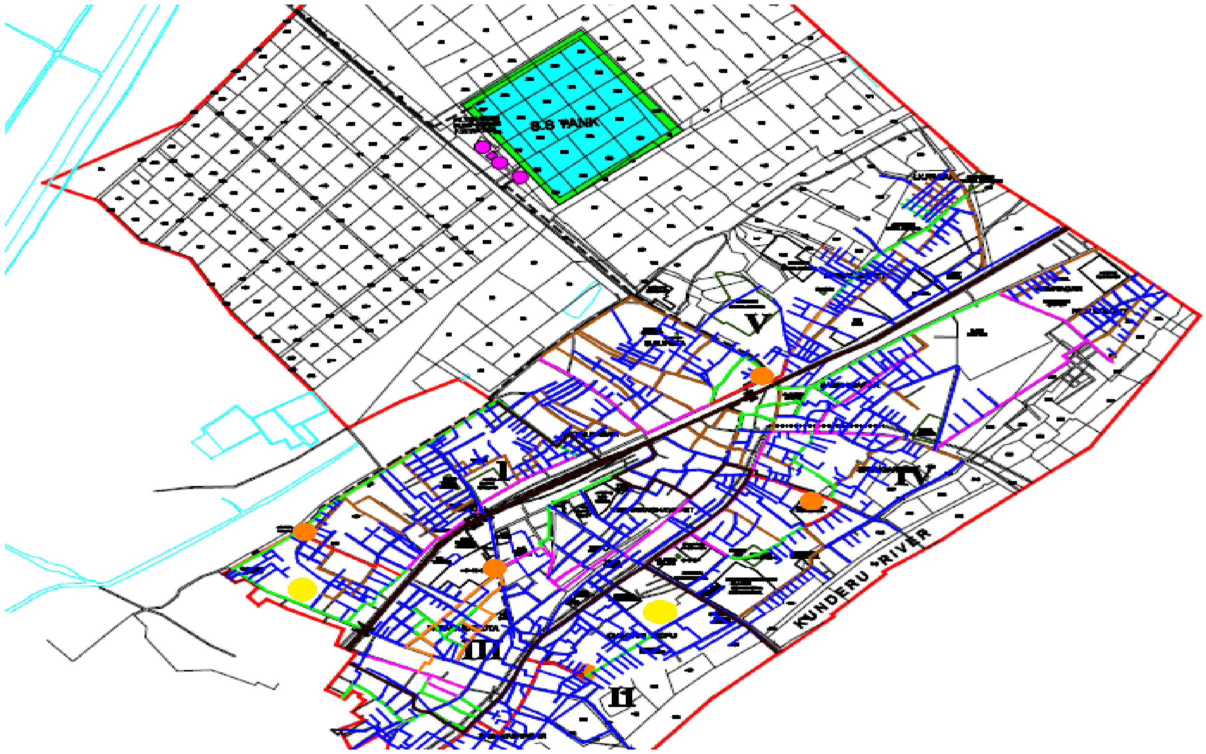

Fig 5 Location of Newly Proposed Reservoirs in Chirala Map

Existing reservoirs

Newly proposed reservoirs

The design capacity of the existing distribution network is 15.44 MLD which is not sufficient for the future design demand of 19.08 MLD. Hence the two reservoirs must bare a capacity to suppress the excess demand.

Let the capacity of the reservoirs may be chosen as 2 MLD each. These reservoirs may be joined with the designed network at the proposed locations.

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